

# Answer Key

## Physics Experiments

### DYNAMICS

#### Newton's First Law of Motion

Newton's first law states that every body remains in a state of constant velocity unless acted upon by an external unbalanced force. In other words, an object that is at rest will remain at rest unless another object with enough force sets it in motion. At the same time an object that is in motion, will continue to be in motion unless something acts to slow it down or stop it.

This experiment will ultimately help the children understand this concept. The washers that are stacked one on top of the other will not move. There is nothing around them that will set them in motion. If one of the children touches them or takes his finger and moves them they will not move.

On the other hand the washer that they will flick is set in motion by their finger. That washer now has no reason to stop moving unless some force around it causes it to stop. In an ideal environment where there is no such forces around then the washer would continue moving. On earth however, we have gravity, and friction. Both of these forces will ultimately take their toll and cause the washer to move.

When the washer moves towards the stack of washers it will encounter a force and that force being the washers that are not moving. The energy that is in the moving washer will be passed on to the non-moving washers which in turn will begin moving.

#### Newton's Second Law of Motion

Newton's second law states that acceleration is produced when a force acts on a mass. The greater the mass (of the object being accelerated) the greater the amount of force needed (to accelerate the object).

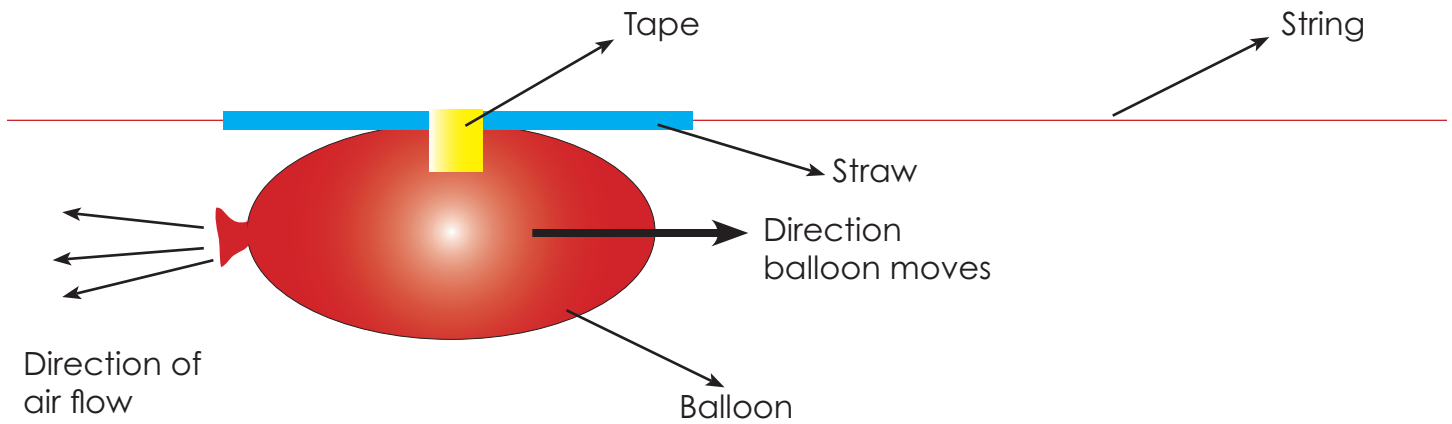
Everyone unconsciously knows the second law. Experientially we are all aware that heavier objects need more force to move the same distance as lighter objects.

This experiment helps to show just this relationship! for advanced students you can begin developing the idea that there is a relationship between these three values: Force, mass, and acceleration. The final formula being  $F=m \cdot A$  or Force equals mass times acceleration.

#### Newton's Third Law of Motion

Newton's third law states that for every action there is an equal and opposite re-action.

The idea behind this experiment is to show the children the meaning of equal and opposite re-action. To do this you will need to set up the experiment. The following figure should help.



As the air from the balloon moves out the balloon is pushed forward. Have the students experiment with the quantity of air that is inside the balloon and the distance traveled. What they will need to realize is that the more air that the balloon contains, the farther the balloon will travel. In reality the distance the balloon travels will be proportional to the volume of the air that is inside the balloon.

### **What is your speed?**

The speed with which we perform certain tasks often depends on the amount of practice we have given ourselves in performing these tasks. This aside, the speed with which we perform a task for the first time is a good indication of how our brain process information and in turn is interpreted by our muscular system.

The tasks that the children as asked to perform in this experiment will result in various times. However, the idea here is to understand that distance is connected to time and speed. The old formula  $d=r \cdot t$  (distance equals rate times time) will come into play here as the children discover its meaning. Please note that you can substitute speed in place of rate.

### **Speed Chomps!**

This experiment is similar to the previous experiment "What is your speed?"

Suggestion, you might want to divide your students and have some of them perform What is your speed while the other half can perform Speed Chomps! Once completed they can share their results with the class so that they can see the relationship that exists.

# **ELECTRICITY**

## **Changing Resistance**

Pencil lead is made of graphite. Graphite is the only non metal that is a good conductor of electricity.

In the “Old - days” lead was a mixture of graphite and the metal lead. However, today this is not the way it is. Today’s pencil leads are a combination of graphite and clay. The more clay, the harder the “lead” in the pencil. Therefore, today, what we have in a pencil is the same thing found in a resistor, a composition resistor, as opposed to a metallic or wire-wound resistor. The more clay, the poorer conductor it is (this is why we advise that you use a soft pencil), the higher the resistance value. It is just that a common resistor is calibrated and the pencil lead is not. So, in a sense it IS a conductor, but only a partial conductor, which makes it effectively a resistor.

## **Discovering Electricity**

Prepare ahead of time a kit for each group of two or three students. If students work in larger groups, some will not get hands on experience. Each kit will include a brown lunch sack, one C cell battery, two insulated copper wires, one battery holder and two brass battery clips, one small flashlight bulb, and socket. All these items must be separate and in random order in the bag. The bag must be closed.

1. Give each group of students a bag and allow 10 minutes for exploration. During this time, you the teacher must remain quiet unless asked a question. The students will be very busy trying to find out what to do with the contents of the bag. Do not give any clues as to use of the contents. This is exploration time.
2. Before the 10 minutes are up some students will undoubtedly have made a simple circuit with the contents of the bag. At this time, you can stop for discussion.
3. After all students have been successful with the simple circuit, each pair must draw what they have done in their science log or on a piece of paper. Older kids will label all the parts of the circuit, etc.

## **Electrical Appliances**

Answers will vary for this activity based on what appliances each student has available at his/her home. Have the students try to understand that older appliances are usually more inefficient and cost more to operate.

## **How Temperature Affects a Solar Cell**

In this experiment the students will discover that the amount of energy that a solar panel produces is closely related to the temperature. Under ideal conditions the students will observe that the power produced by a solar panel will reach a peak. Following that peak

as the temperature increases the output will begin to decrease. Usually expect to see a 40% decrease in the amount of energy produced as the temperature increases.

## **Maximizing Solar Energy**

To get the most from solar panels, you need to point them in the direction that captures the most sun. But there are a number of variables in figuring out the best direction.

Based on the directions for this experiment you are to assume that the panel is fixed, or has a tilt that can be adjusted seasonally. (Panels that track the movement of the sun throughout the day can receive 10% (in winter) to 40% (in summer) more energy than fixed panels. This is a concept that the students will ultimately come to realize directly or indirectly. You can also ask them the question if you see that this concept is escaping them.

Solar panels should always face true south if you are in the northern hemisphere, or true north if you are in the southern hemisphere. True north is not the same as magnetic north. If you are using a compass to orient your panels, you need to correct for the difference, which varies from place to place. Search the web for "magnetic declination" to find the correction for your location.

The next question is, at what angle from horizontal should the panels be tilted? Books and articles on solar energy often give the advice that the tilt should be equal to your latitude, plus 15 degrees in winter, or minus 15 degrees in summer. These are all concepts that you can explore with the groups.

## **HEAT**

### **Hot and Cold Colors**

Hot water tends to be less dense than cold water. For this reason food coloring will usually spread much faster in hot water as opposed to cold water.

### **Hot and Cold**

Answers will vary depending on types of windows that your school has and the types of shading that you are using.

In general terms however, please note that vinyl and plastic coverings will provide a better insulation and will keep heat from reaching the beakers.

### **Energy Roller Coaster**

This experiment is used to show students potential and kinetic energy.

Remember: Potential energy is seen when the marble is at the top of the U track. At that position it has the potential of "doing" an activity or it has potential energy. When the marble

is traveling down the side of the U track it is using the potential energy it had to convert it into kinetic energy. The moment the marble passes the midpoint at the bottom of the U track the kinetic energy begins to transform into potential energy as the marble continues to climb up the opposite side of the U. When the marble turns around and moves the other way the potential energy is converted back to kinetic and so on.

Eventually the marble will come to a complete stop at the midpoint at the bottom of the track. The energy did not get lost. Instead you want to help the students understand that the energy was converted to heat (through friction) which was lost to the air around the marble.

For the conclusion of this experiment the students should begin to see that energy is transferable. Energy can move between one object and another. Note that this is what was happening with friction. (air molecules)

## **Potential and Kinetic Energy**

Work: Work is the product of force and the distance over which it moves.

Mechanical Energy: Mechanical energy is the sum of potential energy and kinetic energy.

## **Apple Energy**

Answers will vary

## **Heat Energy and Radiation**

The result that students will discover in this experiment is that darker color substances tend to gain heat and lose heat faster. The idea behind this is the amount of light that each color is capable of absorbing or repelling. Remember that white is the result of mixing all colors (wavelengths). The reason you are seeing white is because none of the colors are absorbed instead they are reflected which results in white. Black on the other hand is created because all the colors are absorbed and none are reflected. Since all colors (wavelengths) are absorbed black tends to heat up faster.

## **LIGHT**

### **Novas and Supernovas**

Answers provided

Protection from UV

UV beads can be obtained online. Simply do a search on UV beads and a number of sites will pop up. (i.e. <http://www.stevespanglerscience.com/product/color-changing-uv-beads>)

The idea behind this experiment is to get the students to realize that UV rays are often

harmful. Furthermore, students should realize that UV rays are capable of penetrating a variety of containers and shades.

## **Making the Spectrum**

This experiment will help children understand that light (as we see it or don't see it) is made of several colors. The first thing most students say when see the spectrum is "rainbow." Help the students understand that white light is white because it includes all of the colors they are able to observe in the "rainbow."

## **The Color Wheel**

This experiment is similar to the one before it. It approaches the subject of white light from a different point of view. Again the idea is to have students understand that white light is made from several colors. White itself is not necessarily a color but rather all the colors.

## **How the Brain Sees Light**

Fun activity. Explore why you see what you see. Have the students research and come up with additional activities that "play with your mind."

# **SIMPLE MACHINES**

## **Simple Machines - Levers**

Students should realize that simple machines actually cut down in the amount of work and force required to perform an action.

In general a lever uses a pivot point (referred to as a fulcrum) to reduce the force needed to lift an object through the magical property of SHARED FORCES. The force(s) applied at end points of the lever are proportional to the ratio of the length of the lever arm measured between the fulcrum and application point (where you press) applied at each end of the lever, shown through the formula  $M=Fd$  (in which "F" is the force, "d" is the distance between the force and the fulcrum, and "M" is the turning force known as "torque" or as it's sometimes called, though technically not correct, the "momentum.")

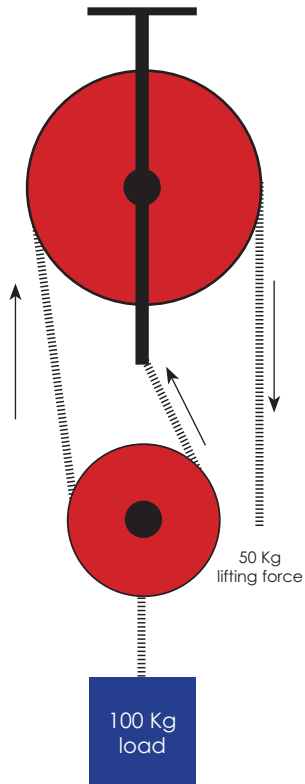
## **Simple Machines - Pulleys**

A pulley is simply a collection of one or more wheels over which you loop a rope to make it easier to lift things. Pulleys are examples of what scientists call simple machines. That doesn't mean they're packed with engines and gears; it just means they help us multiply forces. If you want to lift a really heavy weight, there's only so much force your muscles can supply, even if you are the world's strongest man. But use a simple machine such as a pulley and you can effectively multiply the force your body produces.

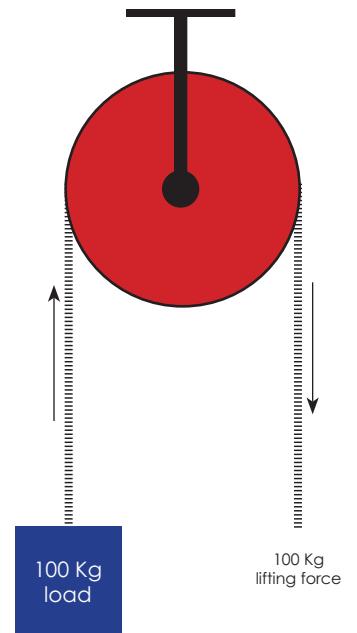
How do pulleys work?

If you have a single wheel and a single rope, a pulley helps you reverse the direction of your

lifting force. So, as in the picture below, you pull the rope down to lift the weight up. If you want to lift something that weighs 100kg, you have to pull down with a force equivalent to 100kg. If you want to raise the weight 1m into the air, you have to pull the rope a total distance of 1m at the other end.

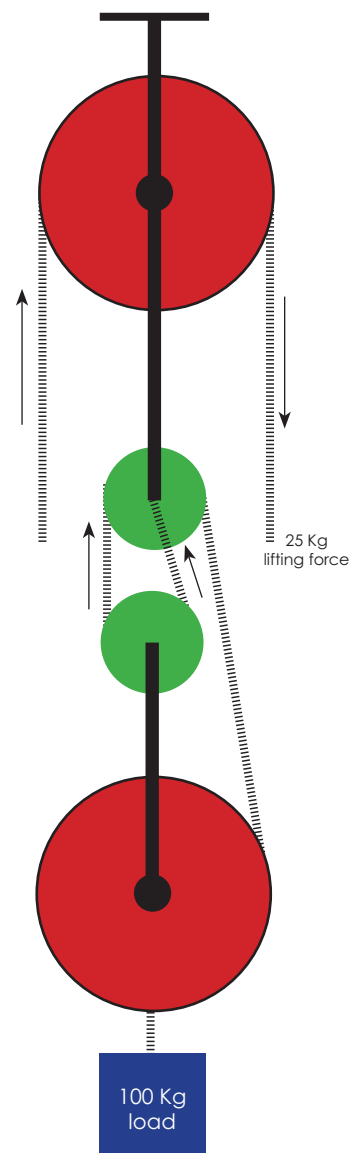


Now if you add more ropes and wheels, you can reduce the effort you need to lift the weight. Suppose you have two wheels and two ropes, arranged as in the figure below. The 100kg weight is now supported by two ropes instead of one (ignoring the loose end of the rope you're pulling with), so you can lift it by pulling with a force of just 50kg—half as much! That's why we say a pulley with two wheels and ropes gives a mechanical advantage (ME) of two. Mechanical advantage is a measurement of how much a simple machine multiplies a force. The bigger the mechanical advantage, the less force you need.



Okay, what if you use four wheels held together by a long rope that loops over them, as in the picture on the right? You can see that the 100kg weight is now supported by four ropes on the left (ignoring the end of the rope you're pulling with). That means each rope is supporting a quarter of the total 100kg weight, or 25kg, and to raise the weight into the air, you have to pull with only a quarter of the force—also 25kg. We say a pulley with four wheels and ropes gives a mechanical advantage of four. That's twice as good as a pulley with two ropes and wheels.

Woodford, Chris. (2011) How pulleys work. Retrieved from <http://www.explainthatstuff.com/pulleys.html>. Accessed (06/29/2011)



## Simple Machines - Inclined Plane

Inclined planes work by increasing the distance the load must be moved, thereby decreasing the force necessary to move the load. An example is pushing a couch up the platform of a moving van. A few people could probably heave the couch up into the van, although it would be difficult; the better solution is to have two people use the ramp to the van (a classic inclined plane) to lift the couch.

Based on this the longer the plank the less the rubber band will stretch.

Technology reference:

Read more: How Does an Inclined Plane Work? | eHow.com [http://www.ehow.com/how-does\\_5122555\\_inclined-plane-work.html#ixzz1Qgn2UZ3v](http://www.ehow.com/how-does_5122555_inclined-plane-work.html#ixzz1Qgn2UZ3v)

[http://www.ehow.com/how\\_5904861\\_determine-work-input-inclined-plane.html](http://www.ehow.com/how_5904861_determine-work-input-inclined-plane.html)

## Simple Machines - Wheels

It is obvious, and many students will quickly realize that wheels do actually decrease the amount of friction that two surfaces generate.

However, how do wheels actually do work?

A wheel is a circular device capable of rotating on its axis, facilitating movement or transportation or performing labour in machines. A wheel together with an axle overcomes friction by facilitating motion by rolling. Common examples are found in transport applications. More generally the term is also used for other circular objects that rotate or turn, such as a Ship's wheel and flywheel.

The wheel (with axle) is considered one of the simple machines and lies near the starting point of advanced human technology (advanced, that is, in comparison with even earlier mechanical innovations such as stone/bone knives and axes, tension-sprung projectiles, scoops and shovels).

When wheels are used in conjunction with axles, either the wheel turns on the axle or the axle turns in a vehicle (as in a cart) or a housing (as in a mill). The mechanics are the same in either case.

Today there are numerous examples of machines that make use of a wheel and axle. However, we can divide them into 5 main categories:

- Crank
- Flywheel
- Reaction wheel
- gyroscope
- windlass

## **Simple Machines - Screw**

Answers will vary depending on the type, size and number of threads that a screw has.

Conclusion Answers:

1. The more threads a screw has the longer the inclined plane would be.
2. Mountain roads actually go around the mountain and are often in a zig zag pattern the reason being that they are trying to implement the inclined plane machine and benefits.
3. No we cannot usually pull out a screw with our fingers. The reason why we use tools is because we would need to add an incredible amount of energy or force to undo the amount of work that the screw has performed. The tools will actually help us cut down in the amount of force that will be used and ultimately the Force.
4. Tools are often developed out of necessity. Farmers often invent their own tools and today many of the tools that we use in our everyday life were actually developed by farmers that needed to make their work easier and quicker.

The rest of the answers will be based on the experiences that each child has acquired. Therefore, answers will vary.

## **Simple Machines - Wedge**

Wedges are yet another form of an inclined plane. Have a discussion with the children in your class so that they can see the similarities and differences that a wedge has with that of an inclined plane.

# **SOUND**

## **Making a Simple Instrument**

Answers will vary

## **Listening to Sound**

Sound is transmitted by particles (atoms or molecules) in a solid, liquid or gas colliding with each other. It is a wave which is created by vibrating objects and propagated through a medium (solid, liquid or gas) from one location to another. A vibrating source can be sound coming from a drum, speaker of a radio, the mouth of a person (vocal chord), a car engine, a plane above the sky and so on. Although sound is commonly associated in air, sound will readily travel through many materials that are solid, liquid and gas.

## **Seeing Vibrations**

What is sound? Sound is a form of energy, just like electricity and light. Sound is made when air molecules vibrate and move in a pattern called waves, or sound waves.

The reason the sand bounces is because sound waves are still being transmitted and are traveling through the air molecules until they collide with the sand particles.

## **Resonance**

Answers will vary

## **Echoes**

The sound was clearer with the foam board. The reason for this is that foam will actually absorb the echo and will keep the sound clean.

This is also the reason why sound studios are lined with foam. The truth about this is that studios are not actually trying to soundproof the space. On the contrary they are trying to keep the feedback from bouncing off the walls and creating an echo.

# Research Question Answers.

## Dynamics

### Card 1

Time of fall, T (s)	1	2	3	4	5	6	7	T
Velocity, v (D/T)	32	64	96	128	160	192	224	32 T

#### Pattern & formula

- The velocity increases by a constant **32 ft s<sup>-1</sup>** each second.
- Because the change in velocity per second is constant, the acceleration is 32 ft s<sup>-2</sup> ( $\approx 9.8 \text{ m s}^{-2}$ ).
- A concise algebraic form is  **$v(T) = 32 T \text{ ft s}^{-1}$**  (or  $\sim 9.8 T \text{ m s}^{-1}$  if the table were metric).

#### Space-Needle problem

Seattle's Space Needle drop time = 10 s  $\rightarrow$

$v = 32 \times 10 = \mathbf{320 \text{ ft s}^{-1}} \approx 97.5 \text{ m s}^{-1}$  (about 219 mph).

A complete student answer should

- fill the table correctly,
- state the direct proportionality  $v \propto T$ ,
- and apply it to the 10 s case with units.

### Card 2

Time, T (s)	1	2	3	4	5	6	7	T
Distance, D (m)	16	64	144	256	400	576	784	16 T <sup>2</sup>

#### Pattern & formula

- Dividing each distance by 16 yields 1, 4, 9, 16, 25...  $\rightarrow$  perfect squares.
- Therefore  **$D = 16 T^2 \text{ ft}$**  (or  **$D = 4.9 T^2 \text{ m}$**  in SI).

A good student response highlights

- the square-of-time relationship,
- recognition that 16 ft  $\approx 4.9 \text{ m}$  represents  $\frac{1}{2} g$ ,
- and the proportional-to-T<sup>2</sup> law that later became  **$s = \frac{1}{2} g t^2$** .

## Card 3

### Exemplar interview outline

**Galileo:** Master Aristotle, I climbed the tower and dropped a 1-lb and a 10-lb cannonball together. They struck the ground at the same moment.

**Aristotle:** Impossible! Heavier bodies seek their natural place faster than light ones.

**Galileo:** Only if air drags differently, sir. In a vacuum the resistance disappears; mass does not change the rate of fall.

**Aristotle:** Your vacuum is an abstraction.

**Galileo:** True, but mathematics lets us isolate variables. Motion continues in a straight line not because a force keeps pushing, but because **no net force** acts to change it—what we now call inertia.

**Aristotle:** Then why do carts roll to a stop?

**Galileo:** Friction, not a decay of "impetus". Remove friction and the cart keeps rolling.

**Conclusion (teacher note):** Look for students to cite (i) vacuum thought-experiment, (ii) tower drop, (iii) role of friction/air resistance, (iv) concept of inertia replacing Aristotle's "natural motion".

## Card 4

### 1. Definitions

- **Geocentric model:** Earth fixed at the center; Sun, Moon, planets, stars revolve around it (Ptolemy).
- **Heliocentric model:** Sun at the center; Earth both orbits the Sun and rotates daily (Copernicus, championed by Galileo).

### 2. Simple diagram description

- *Geocentric:* Concentric crystal spheres with Earth at the center, Moon on the first sphere, then Mercury, Venus, Sun, Mars, Jupiter, Saturn, fixed stars.
- *Heliocentric:* Sun central; Mercury, Venus, Earth (+ Moon), Mars, Jupiter, Saturn travel in elliptical paths.

### 3. Why geocentrism was persuasive

- Everyday perception: the ground feels still while Sun rises and sets.
- Aristotelian physics required a central, motionless Earth.
- Lack of detectable stellar parallax with naked eyes.

### 4. Why heliocentrism troubled Church authorities

- Certain Biblical passages ("Sun stood still...") seemed literal.
- Undermined the longstanding unity of Aristotelian philosophy with Scholastic theology.
- Galileo's 1632 *Dialogue* appeared to ridicule the Pope's geocentric stance, leading to the 1633 Inquisition trial.

*Teacher look-fors:* mention of telescopic evidence (Jupiter's moons, Venus's phases), parallax, scripture conflict, Inquisition outcome.

## Card 5

### Forces and motion sequence

Moment	Forces acting	Explanation via Newton's Laws
At rest on table	Weight $W = mg$ downward; normal force $N$ upward (equal & opposite)	Balanced $\rightarrow$ no acceleration (1st law, equilibrium)
Hand pushes ball	Brief horizontal push $F_{\text{push}}$ ; $N$ & $W$ still balance vertically	2nd law: $F = ma \rightarrow$ ball gains horizontal velocity
Just after leaving edge	Only $W$ downward; negligible air drag in ideal model	1st law horizontally (constant $v_x$ ); 2nd law vertically ( $a_y = g$ )
In flight (projectile)	$W$ downward; small air resistance $F_{\text{drag}}$ opposite velocity	Path is parabolic; 3rd law seen between ball & Earth (ball pulls Earth up slightly)
Impact with floor	Normal force from floor dramatically upward, larger than $W$ ; deformation friction	Impulse reverses vertical velocity; some energy to sound/heat

### Diagram expectations

A labelled sketch should mark

- $v_x$  (horizontal) constant arrow;
- $v_y$  increasing downward;
- weight, normal, push, drag vectors;
- parabolic trajectory.

Students should explicitly connect each stage to the **three laws**.

## Card 6

### Key points an accurate answer should cover

1. **Coefficient of friction ( $\mu$ )** between rubber and dry asphalt is high ( $\sim 0.7$ ). Water acts as a lubricant, reduces  $\mu$  ( $\leq 0.4$ ) and can create a thin film  $\rightarrow$  **hydroplaning** where  $\mu \approx 0$ .
2. **Stopping distance  $d = v^2 / (2\mu g)$** . Lower  $\mu \rightarrow$  longer  $d$ .
3. **Accident-rate increase**: Drivers often maintain dry-road speeds; longer stopping distance + poorer visibility = more rear-end and loss-of-control collisions.
4. **Inertia link (1st law)**: A moving car tends to keep its velocity. Brakes apply a backward force via friction. When  $\mu$  falls, that force is smaller, so deceleration ( $a = F/m$ ) is smaller  $\rightarrow$  the car "wants" to keep going.
5. **Other notes**: Anti-lock braking systems (ABS) modulate brake pressure to keep wheels turning and retain static friction; tread channels water away.

## Card 7

1. **Balanced forces (equilibrium):**  $\Sigma F = 0 \rightarrow$  no acceleration. Example: book on desk with  $N = W$ .
2. **Definition of the unit**
  - **Name:** newton
  - **Symbol:** N
  - **Formal definition:** The force required to accelerate a **1 kilogram mass by 1 meter per second squared**.
  - **Dimensional form:**  $\text{kg}\cdot\text{m}\cdot\text{s}^{-2}$ .

A robust student answer should note all three elements above.

## Card 8

### Precise definitions

Term	Formal definition	Essential distinctions
Speed (scalar)	Rate at which distance is covered; $s = d / t$	Magnitude only, no direction
Velocity (vector)	Displacement per unit time; $v = \Delta x / t$	Direction <b>and</b> magnitude
Acceleration (vector)	Rate of change of velocity; $a = \Delta v / t$	Can change magnitude, direction, or both

### Bicycle ride illustration

*You pedal 60 m east from your driveway to the corner in 20 s.*

*—Average speed:  $60 \text{ m} / 20 \text{ s} = 3 \text{ m s}^{-1}$ .*

*—Velocity:  $3 \text{ m s}^{-1}$  east (direction specified).*

*Half-way you speed up—from  $2 \text{ m s}^{-1}$  to  $4 \text{ m s}^{-1}$  in 4 s.*

*—Acceleration:  $(4 - 2) \text{ m s}^{-1} / 4 \text{ s} = 0.5 \text{ m s}^{-2}$  east.*

*Reaching the stop sign you brake to rest in 3 s; acceleration is  $-1.33 \text{ m s}^{-2}$  (opposite direction of motion).*

A complete student answer should

- distinguish scalar vs. vector,
- give correct formulas with units,
- and weave the three terms into a coherent real-world narrative.

# Research Question Answers.

## Electricity

### Card 1

#### What "induction" means here

- *Electrostatic induction* is the redistribution of electric charge on an object caused by the electric field of a nearby charged object without direct contact.
- In a thundercloud, violent up- and downdrafts separate charges: the cloud base accumulates **negative** charge; the upper cloud carries **positive** charge.
- The negative base repels electrons in the ground, leaving the surface soil, buildings, and trees **positively** charged.

#### Diagram expectations

- Label a towering cumulonimbus; shade the lower half "-", upper half "+".
- Show the ground surface beneath with "+" signs; include a stepped leader descending and upward streamers rising.
- Indicate the lightning channel where opposite charges neutralize.

#### Key explanation students should give

- Because opposite charges attract, the strong electric field (often  $> 3 \text{ MV m}^{-1}$ ) finally breaks down the air's insulation, producing a return stroke that equalizes potentials and **heats the channel to ~30 000 K**—the flash and thunder.

### Card 2

#### Experimental setup

- Galvani (1780s) used a freshly dissected frog.
- When a brass hook in the frog's spinal cord touched an iron railing, the leg muscles twitched.

#### Galvani's conclusions

1. **"Animal electricity."** He proposed the frog's nerves stored electrical fluid released by contact, analogous to Leyden-jar charges.
2. The metals, he thought, merely conducted the electricity already inside living tissue; the twitch proved **vital energy** existed.

#### What was really happening (for teacher reference)

- Contact of two dissimilar metals (Cu-Zn, Fe-Cu, etc.) created a **galvanic cell**; the small current depolarized nerve membranes, triggering contraction.
- Thus the electricity was external, not intrinsic; nevertheless, Galvani's careful observations founded electrophysiology.

## Card 3

### Volta's reinterpretation

- He argued the metals, not animal tissue, generated the current through chemical action.

### How the pile works

Layer	Role
Zn disk	More reactive (oxidized): $\text{Zn} \rightarrow \text{Zn}^{2+} + 2 \text{e}^-$
Brine-soaked cardboard or cloth	Electrolyte: completes ionic circuit
Cu disk	Receives electrons; reduction occurs at Cu/electrolyte interface

Stacking many Zn-electrolyte-Cu "cells" in series raises the total electromotive force (EMF). Electrons flow from Zn (negative terminal) up the stack to Cu (positive terminal).

### Unit named for Volta

- The **volt (V)**—one joule of energy per coulomb of charge—honors him and measures electric potential difference.

## Card 4

### Unit for current

- **Ampere (A)**, named after **André-Marie Ampère**; defined (modern SI) via the elementary charge flow of 1 coulomb per second.


### Unit honoring George Ohm

- **Ohm ( $\Omega$ )**, the SI unit of electrical resistance;  $1 \Omega = 1 \text{ V} / \text{A}$  according to **Ohm's law**  $V = IR$ .

A solid student answer should relate current to charge flow ( $I = \Delta Q / \Delta t$ ) and may cite Ohm's discovery that, for many conductors at constant temperature, resistance is constant.

## Card 5

### Essential parts of Edison's 1879 bulb

Part	Function	Improvement	
High-resistance carbonized bamboo filament	Emits light when hot (~2500 K)	Long life (≈1200 h) vs. earlier low-resistance platinum wires that burned out quickly	
Glass envelope evacuated to $\approx 10^{-2}$ atm	Prevents filament oxidation	Prior bulbs had poorer vacuums → rapid burning	
Support wires & sealed platinum lead-ins	Conduct current, maintain airtight seal	Minimizes leaks/thermal expansion mismatch	
Edison screw base	Reliable, standardized socket	Enabled mass adoption	

### Why 25 W is dimmer than 100 W

- Lamp power  $P = IV = V^2/R$  at fixed mains voltage.
- A 25 W bulb has **higher resistance**, so it draws less current, heats to a lower filament temperature, and radiates less light than a 100 W bulb.

Students should include a labeled sketch showing filament, envelope, and base, and explain thermal radiation intensity  $\propto T^4$  (Stefan–Boltzmann law).

## Card 6

Feature	Series	Parallel
Path	One single loop; current is the same through all loads	Branches; voltage is the same across each branch
Add a bulb	Total resistance <b>increases</b> → current drops → all bulbs dimmer	Each new branch adds conductance; other bulbs stay near full brightness
Failure of one bulb	Opens the circuit; <b>all bulbs go out</b>	Only that branch opens; others remain lit
Typical uses	Christmas-tree light strings (older type), battery chains	Household wiring, multitap power strips

### Closed vs. open circuit

- Closed circuit:** a complete conductive path; charges can flow—switch **ON**.
- Open circuit:** path broken (switch open, filament burnt, fuse blown); current = 0.

Encourage students to sketch both arrangements with ammeter placement to reinforce current/voltage distinctions.

# Research Question Answers.

## Heat

### Card 1

Scale	Historical anchors	Zero-point & interval logic	Everyday or scientific value
Fahrenheit (°F)	1720s, Daniel Fahrenheit; ice–salt slurry (0 °F), pure-ice melt (32 °F), healthy human blood (≈ 96 °F, later reset to 98.6)	180 equal divisions between ice–water and boiling–water (212 °F)	Fine-grained for daily weather (each degree ≈ 0.56 °C) and indoor comfort
Celsius / Centigrade (°C)	1740s, Anders Celsius; original upside-down scale later inverted by Linnæus	100 steps from melting ice (0 °C) to boiling water (100 °C) at 1 atm	Decimal simplicity matches SI prefixes; quick mental sense of freezing/boiling
Kelvin (K)	1848, William Thomson (Lord Kelvin); extrapolated absolute zero where particle motion stops (−273.15 °C)	Same size degree as Celsius but starts at 0 K (absolute zero)	Required for gas-law and thermodynamic equations (no negative temps, directly proportional to internal energy and radiation power via $T^4$ )

A strong student response should (1) state the physical fixed points each scale chooses, (2) explain why Celsius/Fahrenheit are convenient for day-to-day phenomena, and (3) note that Kelvin's absolute baseline makes it indispensable in scientific formulas such as  $PV = nRT$  and black-body radiation.

### Card 2

#### Paddle-wheel experiment (1845)

Joule let heavy weights fall, turning a paddle immersed in water inside a calorimeter. By measuring the mass × height lost by the weights (mechanical work) and the precise temperature rise of the water (heat gained), he showed **4.18 J of work raised 1 g of water by 1 °C**—demonstrating the mechanical equivalent of heat and establishing energy conservation.

#### Definition of the joule (J)

1 J = 1 newton·metre = the energy transferred when a 1 N force moves its point of application 1 m in the direction of the force. It is equally the work required to pass an electric charge of 1 C through a potential difference of 1 V or the heat that raises 0.239 cal of water by 1 °C.

A complete answer links the experimental set-up to the abstract SI unit and notes that the joule measures **mechanical, electrical, and thermal energy alike**—the cornerstone of the first law of thermodynamics.

### Card 3

Key insights students should uncover while analysing household bills or survey check-boxes:

- **Major heat losses**—poor wall/attic insulation, single-pane windows, unsealed ductwork, standby power on electronics, and inefficient incandescent lighting that converts > 90 % of electrical energy to waste heat.
- **Behavioural factors**—thermostat settings, long hot-water showers, open fridge doors, idle car engines.
- **Actionable strategies**—installing weather-stripping and roof insulation, switching to LED bulbs and ENERGY STAR appliances, using programmable thermostats, routine HVAC maintenance, car-pooling or cycling, and composting food waste to cut methane.
- **Quantitative reflection**—students should estimate their household's annual kWh or therms, compare with regional averages, and compute potential savings (cost + CO<sub>2</sub>) from two or three upgrades.

Look for data-driven arguments (e.g., "replacing ten 60 W bulbs with 8 W LEDs saves ~1 kWh day<sup>-1</sup>, ~365 kWh yr<sup>-1</sup>, preventing ~260 kg CO<sub>2</sub>").

### Card 4

#### Five solid examples of potential energy

1. Water behind a dam (gravitational)
2. A compressed spring in a wind-up toy (elastic)
3. Chemical bonds in gasoline before combustion (chemical)
4. A charged capacitor in a camera flash (electrostatic)
5. Position of an electron on a higher orbital shell (atomic/electro-potential)

#### Five solid examples of kinetic energy

1. A rolling bowling ball (translational)
2. Spinning turbine blades in a wind farm (rotational)
3. Vibrating atoms in hot steam (thermal microscopic motion)
4. An electromagnetic wave travelling from a TV transmitter (radiative)
5. Flowing river water driving a hydroelectric plant (fluid kinetic)

A good student answer should define **energy of position** vs **energy of motion**, classify each example correctly, and may include the formula  $KE = \frac{1}{2} mv^2$  as supporting evidence.

## Card 5

Question	Physics reasoning	Typical conclusion
Which has more energy: a baseball ( $\approx 0.145$ kg) or a basketball ( $\approx 0.62$ kg) thrown at the same speed?	$KE = \frac{1}{2} mv^2 \rightarrow$ larger mass yields larger KE	Basketball
Which hurts more on impact: baseball vs tennis ball at same speed?	Similar size $\rightarrow$ similar contact area; baseball mass three-times higher $\rightarrow$ KE higher $\rightarrow$ greater momentum, shorter stopping time $\rightarrow$ more force	Baseball
Does the energy depend on who throws?	Yes: different pitchers impart different launch speeds; $KE \propto v^2$ , so modest speed increases give big KE gains	Stronger throw = greater KE

### Hands-on trial

Students can roll objects of differing mass down a ramp into a sand tray to measure crater depth or use motion sensors/photogates to capture  $v$  and compute KE. A full answer must connect observations back to **mass–speed interplay** and cite the quadratic dependence on speed. Physical Science - Heat...

## Card 6

- 1. Generation** – Proton–proton fusion in the Sun’s core releases  $\gamma$ -rays and kinetic energy.
- 2. Transport through the Sun** –
  - **Radiative zone:** photons random-walk outward over  $\sim 170\,000$  yr.
  - **Convective zone:** rising hot plasma carries energy to surface.
- 3. Solar surface & atmosphere** – Energy emerges as visible light, infrared, ultraviolet, and solar wind; passes chromosphere and corona.
- 4. Interplanetary space** – Photons travel  $\sim 8$  min to Earth; flux at top of atmosphere  $\approx 1361$  W m<sup>-2</sup> (the solar constant).
- 5. Earth’s magnetosphere** – Deflects high-energy charged particles; light continues.
- 6. Atmospheric filtering** –
  - Thermosphere/ionosphere absorb X-rays,  $\gamma$ , most UV-C.
  - Ozone layer (stratosphere) blocks remaining UV-B/-C.
  - Clouds and aerosols reflect  $\sim 20$  %.
  - Air molecules scatter  $\sim 6$  %.
  - About **50–55** % of initial solar power reaches land-and-sea surfaces as short-wave radiation.
- 7. Surface processes** – Absorbed energy heats ground and water, drives evaporation (latent heat), weather, photosynthesis, and ultimately almost all food chains.

Students should sketch the path, label atmospheric layers, quantify the **albedo loss ( $\sim 30$  %)** and atmospheric absorption ( $\sim 20$  %), and note that  **$\sim 70$  % of the incoming energy is dissipated or re-radiated back to space, leaving  $\sim 1.74 \times 10^{17}$  W absorbed by Earth at any moment.**

# Research Question Answers.

## Light

### Card 1

Feature	Convex (Converging)	Concave (Diverging)
Shape	Thicker at center than edges (double-convex or plano-convex)	Thinner at center than edges (double-concave or plano-concave)
Manufacture	Precision grinding/polishing of glass or polymer into outward-bulging surfaces; radius selected to set focal length $f$	Same techniques, but surfaces are hollowed inward; negative radius of curvature
Light path	Refracts incident parallel rays <b>toward</b> the principal axis, meeting at the focal point $f$ (real focus)	Refracts rays <b>away</b> from axis; virtual focus appears on object side at distance $-f$
Image results	Real, inverted image if object beyond $f$ (camera lens), virtual upright image if object inside $f$ (magnifying glass)	Always virtual, upright, reduced image (peephole viewer, laser beam expander)
Key uses	Cameras, eyeglass correction for hyperopia, microscopes, telescopes (objective), solar cookers	Eyeglass correction for myopia, Galilean telescope eyepiece, safety "spy" mirrors

*Essential student explanations:* state Snell's law ( $n_1 \sin \theta_1 = n_2 \sin \theta_2$ ), relate curvature difference to refraction angle, include ray diagram with principal axis, focal points, and at least two refracted rays for each lens type.

### Card 2

#### Core parts students should label in a drawing

1. **Objective lens (convex, short  $f$ )** – creates enlarged real image inside tube.
2. **Body tube** – fixed length  $L \approx 160$  mm between objective and eyepiece in standard designs.
3. **Eyepiece / ocular (convex)** – acts as magnifier, turning real image into larger virtual image for eye.
4. **Stage** – platform with clips for specimen slide; fine aperture admits light.
5. **Mirror or lamp** – reflects/transmits illumination through condenser (Hooke's early scopes used an external oil lamp).
6. **Condenser lens (later addition)** – focuses light onto specimen, improving contrast.
7. **Focusing mechanism** – rack-and-pinion or screw to vary objective-to-specimen distance.

*Good answers* also note Hooke's landmark use of **multiple lenses (compound)** to reach total magnification  $M \approx (m_1 \times m_2)$ . Students might cite his 1665 *Micrographia* drawings (fleas, cork "cells").

### Card 3

Researcher	Method	Result
Jean Foucault (1850)	Rotating mirror + fixed mirror separated by $\approx 20$ m; angular deflection of returning beam reveals transit time	298 000 km s <sup>-1</sup> (within 0.6 % of modern value)
Albert A. Michelson (1879–1926 series)	Improved Foucault; later 1926 Mt. Wilson test used 35 km path across Mojave Desert with rotating eight-sided mirror at 528 Hz	299 796 $\pm$ 4 km s <sup>-1</sup>

**Nobel Prize** – 1907 (first physics Nobel to a U.S. scientist) for precision optical instruments and speed-of-light determinations.

#### Modern constant (CIPM 1983)

*The International Committee on Weights and Measures (CGPM)* defines the speed of light in vacuum as **exactly**

$$c = 299\,792\,458 \text{ m s}^{-1}.$$

The symbol **c** (from *celeritas*, Latin for swiftness) is used universally.

Student responses should describe rotating-mirror geometry, explain how time =  $(\Delta\theta / \omega)$  relates to path length, and quote the accepted fixed value and symbol.

### Card 4

Term	Concise definition	Essential diagram elements
<b>Lumen (lm)</b>	SI unit of luminous flux: light power weighted by human eye response; 1 lm = 1 cd·sr	Draw lamp emitting cone of 1 steradian from 1 candela source; shade area marked "1 lm"
<b>Candela (cd)</b>	SI base unit of luminous intensity: flux per steradian from monochromatic 540 THz source radiating 1/683 W sr <sup>-1</sup>	Same lamp: label intensity arrows 1 cd into each steradian
<b>Umbra</b>	Region of <b>total</b> shadow where light source is completely blocked	Sun–Moon–Earth eclipse sketch: narrow dark cone reaching Earth
<b>Penumbra</b>	Region of <b>partial</b> shadow where source is only partly blocked	Extend diagram to wider, lighter gray cone around umbra

*Grading hints:* look for correct connection between lumen (flux) and candela (intensity), and accurate shadow geometry with parallel-ray construction.

## Card 5

Color	Wavelength $\lambda$ (nm)	Frequency $f$ (THz)
Red	~700 nm	Lowest (~430 THz)
Orange	~620 nm	480 THz
Yellow	~580 nm	520 THz
Green	~550 nm	545 THz
Blue	~470 nm	640 THz
Violet	~400 nm	Highest (~750 THz)

**Order mnemonic** – ROY G. BV (red, orange, yellow, green, blue, violet) ascending frequency / descending wavelength.

A strong student answer cites the inverse relationship  $f = c/\lambda$ , lists either wavelengths or frequencies with proper units, and notes that indigo is sometimes inserted between blue and violet historically.

## Card 6

### How we see color

- Cones in retina contain photopsins (S, M, L) tuned to peak sensitivities near 420 nm (blue), 534 nm (green), 564 nm (red).
- Objects **emit** (LED, flame) or **reflect** subsets of the incident spectrum; relative cone stimulation maps to perceived hue.

### Types of color-vision deficiency (CVD)

Type	Cones affected	Common name	Prevalence*
Protanopia/protanomaly	L cones absent / altered	Red-weak / red-blind	~1 % males
Deuteranopia/deuteranomaly	M cones absent / altered	Green-weak / green-blind	~5 % males
Tritanopia/tritanomaly	S cones absent / altered	Blue-yellow deficiency	< 0.1 % population
Monochromacy (rod or cone)	Two or all cone classes absent	Total color blindness	< 0.003 %
Achromatopsia from brain injury	Cortical	Cerebral achromatopsia	Very rare

\*Approximate global figures; overall CVD ~8 % of males, 0.5 % of females (X-linked inheritance).

**Student explanations should include**

- Genetics (X-chromosome opsin gene mutations for red-green forms).
- Everyday challenges (traffic lights, wiring resistors, career restrictions).
- Adaptive tools—Ishihara plates for screening; EnChroma spectral-filter glasses; digital accessibility palettes.

# Research Question Answers.

## Magnetism

### Card 1

#### Magnetic vs. geographic North

Aspect	Magnetic North Pole	Geographic North Pole
Definition	Point on Earth's surface where the planet's magnetic field lines are vertical and enter the planet	Northern end of Earth's rotation axis
Location (2025)	Arctic Ocean—about 86° N, 155° E; it drifts ~55 km yr <sup>-1</sup> toward Siberia	90° N latitude, fixed by definition
Navigation effect	A compass points to magnetic north, so angular difference from true north (magnetic declination) varies by position and date	Nautical and geographic maps use this as the reference for latitude/longitude

#### Why Columbus stayed silent

On his first Atlantic crossing (1492) Columbus noticed his compass no longer aligned with Polaris, revealing a declination of a few degrees. He feared that telling the crew would undermine confidence in both his charts and his leadership, so he kept the discrepancy private and adjusted readings quietly.

### Card 2

#### Van Allen radiation belts

- Two main toroidal zones of trapped charged particles guided by Earth's magnetic field.
  - **Inner belt:** 1 000 – 12 000 km above surface, mostly high-energy protons.
  - **Outer belt:** 13 000 – 60 000 km, mainly energetic electrons.
- Strongest over the equator, thickness tapers toward the poles where field lines converge.

#### Aurora formation

1. Solar-wind electrons spiral along field lines toward polar regions.
2. They collide with upper-atmosphere atoms/molecules (~100–300 km altitude), exciting them.
3. De-excitation emits light: oxygen → green (557 nm) and red (630 nm); nitrogen → blue-violet and crimson.
4. Resulting displays are called the **aurora borealis** (north) and **aurora australis** (south).

Students should place the belts on a world map as doughnut-shaped regions around the equator and mark polar ovals where auroras are observed.

## Card 3

Category	Definition	Typical magnetic "pull"	Three clear examples
<b>Ferromagnetic</b>	Materials whose atomic moments align spontaneously, producing strong, permanent magnetization	Very strong	Iron, cobalt, nickel
<b>Paramagnetic</b>	Atoms have unpaired electrons; weakly attracted to a magnetic field; magnetism disappears when field is removed	Weak	Aluminum, platinum, liquid oxygen
<b>Diamagnetic</b>	All electrons paired; induced moment opposes applied field, producing slight repulsion	Very weak (negative)	Bismuth, graphite, water

## Card 4

### NMR (Nuclear Magnetic Resonance)

A spectroscopic technique: nuclei with non-zero spin (e.g.,  $^1\text{H}$ ,  $^{13}\text{C}$ ) absorb and re-emit radio-frequency energy in a strong magnetic field. It reveals molecular structure and dynamics in chemistry and biochemistry.

### MRI (Magnetic Resonance Imaging)

Medical application of NMR. A patient lies in a  $\sim 1.5\text{--}7$  T magnet; pulsed RF fields and gradient coils map the relaxation times of hydrogen nuclei in tissues, generating detailed 3-D images without ionizing radiation.

### Therapeutic magnets

Static magnets sold for pain relief, wound healing, arthritis, etc. Controlled clinical trials have **not** shown reproducible benefits beyond placebo. Evidence supports MRI and NMR for diagnosis, but not static-magnet therapies.

## Card 5

### Two magnetoreception mechanisms

#### 1. Magnetite-based "compass"

- Microscopic magnetite crystals in upper beak nerves detect the field's inclination and intensity, giving birds a built-in map of latitude.

#### 2. Cryptochrome-mediated "visual compass"

- Photopigment cryptochrome in the retina forms radical pairs whose spin states depend on magnetic field direction.
- Birds see a faint, superimposed pattern—often modeled as shifting light–dark or color gradients—that rotates as they turn, aligning body orientation with geomagnetic meridians.
- Learned sky cues (Sun position, star rotation) cross-check the magnetic compass, refining the route through experience.

Magnetism itself does not change visible light wavelengths, but the radical-pair process modulates retinal response, letting birds convert field information into a visual overlay.

## Card 6

- **Hard-disk drives (HDDs)**
    - Thin ferromagnetic layers on spinning platters store bits as regions of magnetization (north-up = 1, south-up = 0).
    - Read/write heads with giant-magnetoresistance (GMR) or tunnel-magnetoresistance (TMR) sensors detect these tiny fields, enabling terabyte-scale storage.
  - **Solid-state drives (SSDs)** use flash memory, but **magnetoresistive RAM (MRAM)** writes bits by flipping magnetic orientation in nano-scale cells—non-volatile, fast, and durable.
  - **Transformers, inductors, and motors** on the motherboard regulate voltages, filter power, and spin cooling fans—all relying on magnetic cores.
  - **Societal impact**
    - Cheap mass storage underpins the data economy—cloud services, digital photos, streaming media.
    - Magnetic sensors (Hall-effect) enable smartphone compasses, image-stabilized cameras, and automotive wheel-speed detection.
    - Emerging spintronic devices promise lower-power, instant-on computing.
-

# Research Question Answers.

## Simple Machines

### Card 1

Lever class	Relative positions	Mechanical advantage (ideal)	Real-world examples
First-class	Fulcrum between effort and load	MA can be $> 1$ , $= 1$ , or $< 1$ depending on distances	Seesaw, crowbar, scissors
Second-class	Load between fulcrum and effort	MA $> 1$ (effort arm longer than load arm)	Wheelbarrow, nut-cracker, bottle opener
Third-class	Effort between fulcrum and load	MA $< 1$ (trades force for speed/range of motion)	Tweezers, baseball bat, human forearm

### Definitions

- **Work** – the product of a force and the distance moved in the direction of that force (  $W = F \times d$  ).
- **Load (resistance)** – the weight or opposing force the lever is meant to move.
- **Fulcrum** – the pivot point about which the lever rotates.
- **Effort (input force)** – the force applied by the user to the lever.

### Sketch guide

Draw a straight beam resting on a triangular fulcrum symbol. Mark the distance from fulcrum to effort (effort arm) and from fulcrum to load (load arm). For first-class levers show effort down, load up; second-class load in middle; third-class effort in middle.

### Card 2

#### *The men behind the units*

- **Sir Isaac Newton (1642 – 1727)** formulated the laws of motion; the SI unit of force is named the **newton (N)** in his honour.
- **James Prescott Joule (1818 – 1889)** showed that mechanical work and heat are equivalent; the SI unit of work and all forms of energy is the **joule (J)**.

#### *When is work being done?*

Work is done **only** when a force produces a displacement **in the direction of that force**. Pushing hard on an immovable wall (no displacement) is zero work; carrying a bag horizontally at constant height does no work against gravity because the force (upward) is perpendicular to motion.

## Card 3

### General definition

$$\text{Mechanical Advantage (MA)} = \frac{\text{load (output force)}}{\text{effort (input force)}}$$

### Formulas for specific simple machines

Machine	Ideal MA expression	What matters
Lever	$MA = \frac{\text{effort arm length}}{\text{load arm length}}$	Geometry: distances from fulcrum
Pulley system	MA = number of rope segments supporting the load	Count the strands actually lifting, ignoring the free (effort) end
Inclined plane	$MA = \frac{\text{length of slope}}{\text{vertical rise}} = \frac{1}{\sin \theta}$	The gentler (longer) the slope, the higher the MA

**Alike:** Each compares how much the machine multiplies force.

**Different:** Each formula reflects the machine's unique geometry—arms on a lever, rope segments in a pulley, slope ratio on an incline.

## Card 4

### *Simple-machine parts*

Component in drawing	Simple-machine type	Role
Central vertical shaft	<b>Wheel-and-axle</b>	Transmits torque from operators to canopy
Helical fabric canopy	<b>Inclined plane (wrapped as a screw)</b>	Forces air downward when rotated, intending to create upward reaction
Hand-cranked bars / winches	<b>Levers</b>	Provide mechanical advantage for human crew
Rope drive	<b>Pulley</b>	Couples human effort to axle (in some reconstructions)

### *Intended operation*

Four men standing on the platform push the side bars, spinning the helical sail. The screw-shaped canopy should "screw" into the air, pushing air molecules downward and generating lift by Newton's third law.

### *Would it have flown?*

Modern analyses show the device was far too heavy, its fabric too porous, and human power far too small to reach the rotational speed needed for lift. It is regarded as an insightful conceptual step, but not a practical flying machine.

## Card 5

Archimedes meant that a **lever of sufficient length** will let a person apply a very small force to move an enormous load, provided there is a solid fulcrum ("a place to stand"). Because torque is the product of force and lever arm, increasing the lever arm lets the required force shrink proportionally.

### *Illustration guide*

Draw a long beam resting on a rock fulcrum close to a huge boulder (the "world"). A tiny stick figure at the far end applies a small downward force; the long distance from fulcrum multiplies this force, overcoming the boulder's weight on the short arm.

## Card 6

### (a) Balancing the two children

Using the law of the lever (moments about the fulcrum):

$$\text{Weight}_1 \times \text{Distance}_1 = \text{Weight}_2 \times \text{Distance}_2$$

Given

- $\text{Weight}_1 = 60 \text{ kg}$ ,  $\text{Distance}_1 = 6 \text{ m}$  (end of the board)
- $\text{Weight}_2 = 40 \text{ kg}$ ,  $\text{Distance}_2 = ?$

$$40 \text{ kg} \times d_2 = 60 \text{ kg} \times 6 \text{ m} \quad \Rightarrow \quad d_2 = \frac{60 \times 6}{40} = 9 \text{ m}$$

The lighter child would need to sit **9 m from the fulcrum**, farther out than the 6 m available, so perfect balance is impossible without extending the plank or adding weight to the lighter side.

### (b) Discovering the law of the lever

From the three data rows in the chart:

$$(\text{Distance}_1)(\text{Weight}_1) = (\text{Distance}_2)(\text{Weight}_2)$$

Examples:

- $5 \text{ m} \times 40 \text{ kg} = 200 \text{ kg}\cdot\text{m}$  and  $2 \text{ m} \times 100 \text{ kg} = 200 \text{ kg}\cdot\text{m}$
- $6 \text{ m} \times 70 \text{ kg} = 420 \text{ kg}\cdot\text{m}$  and  $4 \text{ m} \times 105 \text{ kg} = 420 \text{ kg}\cdot\text{m}$
- $4 \text{ m} \times 75 \text{ kg} = 300 \text{ kg}\cdot\text{m}$  and  $6 \text{ m} \times 50 \text{ kg} = 300 \text{ kg}\cdot\text{m}$

### General formula

$$d_1 W_1 = d_2 W_2$$

where  $d$  is the distance from the fulcrum and  $W$  is the weight (or force).

Students should recognise that equal clockwise and counter-clockwise moments create rotational equilibrium.

# Research Question Answers.

## Sound

### Card 1

#### Famous experiment

- Built two hemispheres of polished copper ( $\approx 50$  cm diameter) that could be clamped together.
- Evacuated the air with a hand-pump, forming a near-vacuum inside.
- Teams of eight horses pulled on each side; despite their effort the halves would not separate until air was readmitted.

#### What he meant to show

- **Horror vacui** ("nature abhors a vacuum"): Guericke wanted to prove that air pressure, not mysterious "suction," holds objects together.
- Separation fails because the external atmospheric pressure ( $\sim 101$  kPa) pushes the hemispheres together when the inside pressure is near zero.

#### Why this challenged earlier beliefs

- Aristotelian tradition claimed true vacuums could not exist.
- Guericke demonstrated that empty space can exist and that **air pressure**—a material property of the atmosphere—explains many phenomena previously assigned to nature's "fear of emptiness."

### Card 2

#### Text explanation

- A sound's source (e.g., plucked string) compresses nearby air molecules.
- These molecules push on adjacent molecules, creating regions of compression and rarefaction that travel outward.
- Because each particle merely oscillates about its equilibrium position, the wave **propagates longitudinally** while the medium does not drift with it.

#### Coiled-spring diagram (verbal guide)

1. Draw a stretched Slinky on a straight line.
2. Squeeze several coils together near the left end (compression).
3. Leave a gap of widely spaced coils next (rarefaction).
4. Repeat the alternating pattern to the right.
5. Add arrows pointing right to label **wave motion**, and tiny double-ended arrows on several individual coils to show **particle vibration** back-and-forth along the spring.

## Card 3

Ear part	Function in hearing
Ear lobe / pinna	Collects sound and funnels it down the auditory canal; its ridges help localise direction.
Eardrum (tympanic membrane)	Thin, taut membrane that vibrates in sync with incoming pressure waves, converting them to mechanical motion.
Ossicles – hammer (malleus), anvil (incus), stirrup (stapes)	Form a lever system that <b>amplifies</b> and transmits eardrum vibrations to the oval window of the inner ear; overall gain $\approx 20\text{--}30$ dB.
Cochlea (fluid-filled spiral)	Incoming motion sets up pressure waves in perilymph; these bend the basilar membrane, stimulating hair-cell receptors that convert mechanical energy to nerve impulses interpreted as sound.

## Card 4

- **Frequency (f)** – number of complete vibration cycles per second; unit **hertz (Hz)**.
- **High pitch**  $\leftrightarrow$  high frequency (short period); **low pitch**  $\leftrightarrow$  low frequency.

Question	Key answer
Human audible range	About <b>20 Hz – 20 000 Hz</b> (20 kHz), best sensitivity near 2–5 kHz.
Threshold of ultrasound	Any sound <b>above 20 kHz</b> . Typical medical ultrasound uses 1 – 15 MHz.

## Card 5

- **Echo-location** – an active sensing method: the animal emits short ultrasonic clicks or chirps and measures the **time delay and intensity** of returning echoes to map its surroundings.

### Bats

- Emit pulses up to 120 kHz.
- Compute distance from echo delay ( $d \approx vt/2$ ) and wingbeat adjustments give flight path clearance down to millimetres.

### Whales & dolphins

- Use lower ultrasonic frequencies (20–160 kHz) that travel farther in water.
- Locate prey, navigate murky depths, and maintain pod communication.

## Card 6

### Definitions

Term	Concise meaning
Doppler effect	Apparent change in wave frequency due to relative motion between source and observer: approaching source → higher pitch, receding → lower pitch.
Sonic boom	Explosive sound heard when an object <b>exceeds the speed of sound</b> ; the piled-up pressure waves merge into a single shock front that reaches the listener.
Shock wave	A thin region of abruptly changed pressure, density, and temperature created when a source travels faster than its wave speed in that medium.

### Doppler radar in weather

- Radar emits microwave pulses; raindrops moving toward or away shift the returned frequency slightly.
- The frequency change reveals wind speed and direction inside storms, enabling forecasters to spot rotation, track fronts, and estimate rainfall intensity.

## Card 7

Item	Date / Speed	Launch or route	Notes
Bell X-1 (Chuck Yeager)	14 Oct 1947; <i>Mach 1.06</i> (~1126 km h <sup>-1</sup> ; 700 mph) at ~13 000 m	Rocket-propelled after being <b>air-dropped</b> from a B-29 bomber at 25 000 ft	Bullet-shaped, alcohol-oxygen rocket, nick-named "Glamorous Glennis."
Concorde SST	Entered passenger service Jan 1976	London/Paris ⇌ New York, Washington, Barbados; typical cruise <i>Mach 2.04</i> (~2 180 km h <sup>-1</sup> ; 1 354 mph) at 18 000 m	Flight paths largely limited to oceanic routes to avoid sonic-boom noise over land, contributing to operational restrictions and eventual retirement (2003).

## Card 8

- **Bel (B)** – logarithmic unit for sound intensity ratio; 1 bel =  $\log_{10}(P_2/P_1)$ .
- **Decibel (dB)** – one-tenth of a bel; 0 dB is the threshold of average human hearing.

Sound source	Typical level
Normal speech (1 m)	≈ 60 dB
Passing car (10 m, urban traffic)	≈ 70 dB
Lawn mower (operator's ear)	≈ 90 dB
Rock concert / nightclub	≈ 110–120 dB

- **Pain threshold** – ~ 130 dB; sustained exposure above 85 dB can damage hearing, and single shocks above 150 dB may rupture the eardrum.